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RADIOGRAPHIC EXAMINATION OF T55 ENGINE.(U)
JAN 78 J T CARROLL DAAJ01-77-C-0354
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Approximately 1000 radiographs and three hours of video fluoroscope tapes of a Lycoming T55-L-712 turbine engine were obtained at various engine operating conditions. These X-ray images were needed to determine certain static and running clearances in the T55 engine.

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FOREWORD

This report describes work performed by Pratt & Whitney Aircraft under Contract DAAJ01-77-C-0354 for the U. S. Army Aviation Systems Command. The work was accomplished in the Pratt & Whitney Aircraft Engine Radiography Test Facility located at Middletown, Connecticut, during the period April 1977 to January 1978.

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SECTION I

INTRODUCTION

A radiographic examination of a Lycoming T55-L-712 turbine engine was required in order to determine certain static and running clearances in the engine. Radiographs taken of the engine operating at various power levels were needed to evaluate deflection and displacement of static and rotating hardware; video fluoroscopy techniques would permit observance of clearances during engine transient operation.

The U.S. Army Aviation Systems Command therefore awarded Pratt & Whitney Aircraft a contract to conduct a radiographic examination of a Government-furnished Lycoming T55-L-712 engine in the Pratt & Whitney Aircraft Engine Radiography Test Facility located at Middletown, Connecticut. In addition to providing the radiographs and video fluoroscope tapes, Pratt & Whitney Aircraft was to prepare a motion picture illustrating the operations performed during the radiographic program. Pratt & Whitney Aircraft would assist the Government in reading the X-ray images and obtaining measurements from them; however, Army and AVCO-Lycoming personnel would interpret the actual significance of the findings.

The following sections of this report describe the radiographic examination program carried out by Pratt & Whitney Aircraft.

SECTION II

DESCRIPTION OF FACILITY

The Pratt & Whitney Aircraft Engine Radiography Test Facility consists of a fully equipped engine test stand designed to accommodate engines with up to 55,000 lb thrust. It incorporates computerized data reduction and is shielded with concrete so that the radiation levels outside the engine test stand are kept below the OSHA limits for X-ray facilities.

The stand is equipped with a Varian Linatron 2000. This 8,000,000-electron-volt X-ray machine is capable of delivering an intensity of 2000 rads/minute — a radiation intense enough to penetrate the largest aircraft engines built.

The X-ray head is mounted in a gantry so that it can be moved over a wide range of positions and angles relative to the engine being tested. Emission of radiation can be pulsed between 80 and 360 pulses per second. This permits strobing the X rays against the engine to "freeze" movement of the parts. The X rays are aimed with a laser, and the point of impingement is readily observed on a closed-circuit television monitor in the control room. After penetrating the engine, the X rays impinge on either a film or an image fluoroscope.

A remotely controlled film transporter, which incorporates a lead-foil intensifying screen, automatically advances the film. The film transport sequence can be preset in the control room to allow multiple images to be obtained during an engine transient, producing a movie sequence of the transient. The film resolution which can be obtained ranges from ± 0.003 inch to ± 0.008 inch.

Film does not provide real-time images. When real-time capability is needed for diagnostic purposes, a high-energy image fluoroscope is used. This device features a special fluorescent screen which was developed to achieve high spatial resolution and conversion of X rays to visible light. This screen utilizes a fiber optic bundle of fluorescent glass having a high index of refraction and high conversion efficiency. The fiber optic bundle is positioned parallel to the X-ray path so the X rays impinge on the ends of the optical fibers. This arrangement increases the interaction of the X rays with the fluorescent material while restricting the scattering of visible light, thereby preserving the image resolution. A reflective shield on the incidence face further reflects light to the viewing surface.

Light from the viewing surface of the fluorescent screen is reflected by a mirror to a Cohu high-resolution, low-light-level Image Isocon television camera that is shielded from the X rays. The image is viewed on a high-resolution (1200-line) television monitor in the control room. The video signal is also recorded on magnetic tape and the image is photographically recorded from a second high-resolution television monitor. The magnetic tape is used to record the complete time history of the video image, frame by frame (30 frames per second). The overall resolution possible from this system, under normal operation, is ± 8 mils.

SECTION III

ENGINE INSTALLATION

A Government-furnished Lycoming T55-L-712 engine (No. M8) to be installed in the radiography test facility was received in Middletown, Connecticut on 11 July 1977.

An overhead adapter was designed and fabricated to permit mounting the T55 engine on the existing JT9D engine hardback in the radiographic test stand. An exhaust duct was designed and fabricated to carry the exhaust from the small Lycoming engine into the existing exhaust ducts. A water supply for the water brake attached to the engine inlet was installed. All the controls and instrumentation needed to operate the engine were installed and adapted to interface with the Lycoming sensors which were incompatible with the Pratt & Whitney Aircraft test equipment already installed on the test stand. These included the hydronic master controls, the water brake interconnecting cables, a 1000-amp, 28-volt dc starter, air and voltage supplies to the water brake, along with the necessary instrumentation to measure the engine performance parameters listed in Table 1. In most cases, the instrumentation to measure these engine performance parameters consisted of sensors provided by Lycoming and readout equipment provided by Pratt & Whitney Aircraft. In the case of torque measurements, however, complete instrumentation systems were provided by Lycoming.

Installation of the engine in the radiographic test facility was completed and ready for testing to begin on 21 July 1977.

TABLE 1. T55 ENGINE PERFORMANCE PARAMETERS MEASURED DURING RADIOGRAPHIC TESTING

Compressor Discharge Static Pressure	Oil Temperature
Oil Pressure	Gas Temperature
Water Brake Pressures:	Waterbrake Temperatures
Water in	Gas Producer Rotor Speed
Water out	Power Turbine Speed
Water to Seal	Waterbrake Support Torque
Lubricant	Engine Torque
Air in	Engine Vibrations (3 locations)
Fuel Pressure	Waterbrake Vibrations
Air Inlet Total Temperatures (4)	

SECTION IV

TEST PROGRAM

ENGINE CONFIGURATION

Three engine configurations were radiographically examined. Configuration No. 1 was the standard bill-of-material T55-L-712 engine. Data from the survey of this engine indicated that the stiffness of the first nozzle (burner exit) resulted in a bumper gap opening different from that anticipated. This bumper was designed to take up the load between the first and third turbine nozzles. To change this bumper gap opening, two modifications were made to the engine.

For engine configuration No. 2, a nozzle was installed without a braze on the inner shroud to give it more flexibility and change the bumper gap opening.

For engine configuration No. 3, the structure was shimmed so that the bumper gap remained open at all times.

ENGINE OPERATING CONDITIONS

Radiographs of various regions in the engine were obtained at the following engine conditions:

- *Cold Static* — In this condition, the engine is not running and has not been run within 16 hours.
- *Hot Static* — In this condition, the engine has just been shut down.
- *Steady-State* — In this condition, the engine is running at a steady power level (idle, intermediate, maximum, or emergency power).
- *Snap Transient* — This transient cycle is produced by "snapping" the power lever from the idle position to the maximum power position or to the emergency power position, maintaining this power level for one minute, and then snapping the power lever back to the idle position. During each of these cycles, eight radiographs are usually taken.
- *Slow Transient* — In this cycle, the engine is accelerated from idle to emergency power over a period of 60 seconds. This power level is maintained for 60 seconds, then reduced from emergency to idle over a period of 30 seconds, after which the engine is shut down. Usually, 24 radiographs are taken during this cycle.

X-RAY LOCATIONS

Radiographs were taken to cover 35 basic regions of interest in the engine, as delineated by AVCO-Lycoming. These regions could be covered by X rays from 24 locations since, in many instances, several of the basic regions of interest would appear together in one radiograph. However, a few views required slight changes in coordinates to include additional information. Also, some of the views containing more than one area of interest required several radiographs taken at different exposure times to achieve the proper contrast for maximum accuracy in extracting data.

The radiographs were obtained by positioning the X-ray source on one side of the engine so that the X rays would pass through the regions of interest and impinge on the film positioned on the opposite side of the engine. The X rays were aimed by a laser beam which indicated the point of impingement on the circumference of the engine.

The major portion of the radiographs were taken with the point of impingement at 0 degrees and with the X-ray head aimed horizontally as shown in Figure 1. Numerous radiographs were also taken with the point of impingement at 180 degrees as shown in Figure 2. Any impingement point above the engine centerline was called "0 degrees"; any point below the centerline was called "180 degrees." For the most part, there was no significant difference between radiographs taken at the top of the engine and those taken at the bottom of the engine at the same axial engine location. A few radiographs were also taken with the point of impingement at 90 degrees (through engine centerline) as shown in Figure 3.

In some special cases, it was necessary to tilt the X-ray head to view certain areas at an angle. One such case was the combustor support pins which lay 45 degrees from vertical. The radiographs of these pins were taken with the X-ray head tilted 35 degrees (the nearest to 45 degrees possible due to equipment limitations) as shown in Figure 4. The second case requiring angle shots was the fuel nozzles. When exposures were made straight across the engine, two nozzles were in alignment, complicating the view. Therefore, radiographs of the fuel nozzles were also taken with the X-ray head tilted 6½ and 7½ degrees as shown in Figure 5.

SUMMARY OF RADIOGRAPHS TAKEN

During the test program, a total of 987 radiographs were taken to permit examination of the 35 areas of interest. The three engine configurations and five operating conditions were represented in these radiographs, as summarized in Table 2.

A more detailed listing of the radiographs is presented in the appendix.

VIDEO FLUOROSCOPY

In a number of instances, the radiographs indicated that real-time observation of the engine operation would be desirable. In such cases, the image fluoroscope was used. All fluoroscope results were recorded on video tape. The video fluoroscope tape recorded during the program runs about three hours. The various engine locations which were viewed by video fluoroscopy are listed in Table 3. As indicated in the table, each of the engine locations was observed in the top portion of the engine (X-ray impingement at 0-degree), the bottom portion of the engine (X-ray impingement at 180-degree), or both.

RADIOGRAPHIC MEASUREMENT

Although responsibility for actual interpretation of the findings in this program rested with Army and Lycoming personnel, Pratt & Whitney Aircraft provided assistance in interpreting the radiographs and extracting measurements from them.

During the data reduction phase, Pratt & Whitney Aircraft representatives made four trips to AVCO-Lycoming to discuss dimensional film-reading techniques. Various methods were pointed out for dealing with ellipsed, blurred, and superimposed images. Some of the ways that improper background densities and inaccurate X-ray beam alignment might affect measurements were explained. Methods of defining edges with transparent tape or suitable overlays and the application of different types of measuring instruments were also demonstrated to Lycoming personnel.

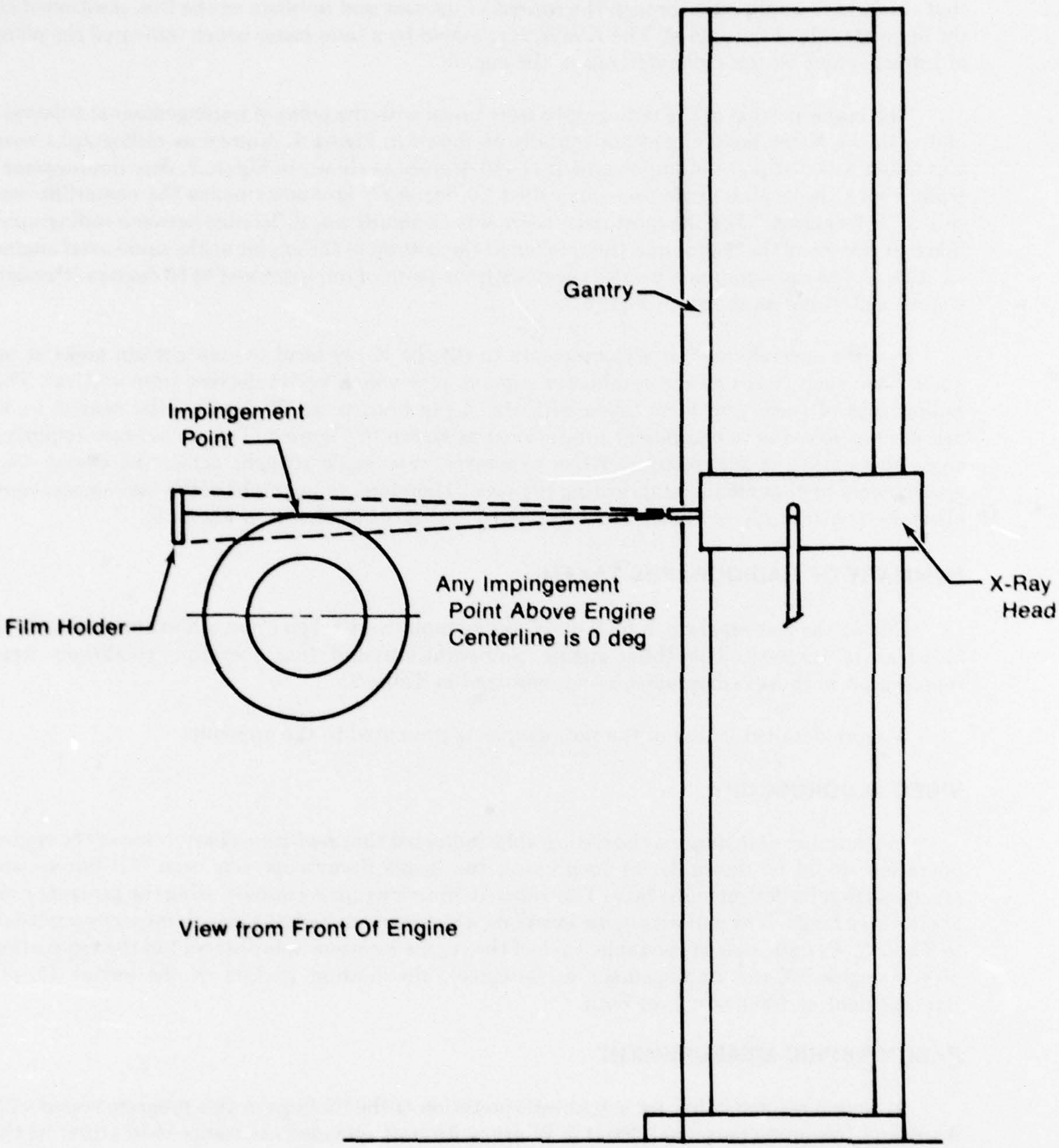

Figure 1. Setup for Taking Radiographs through Top Portion of Engine

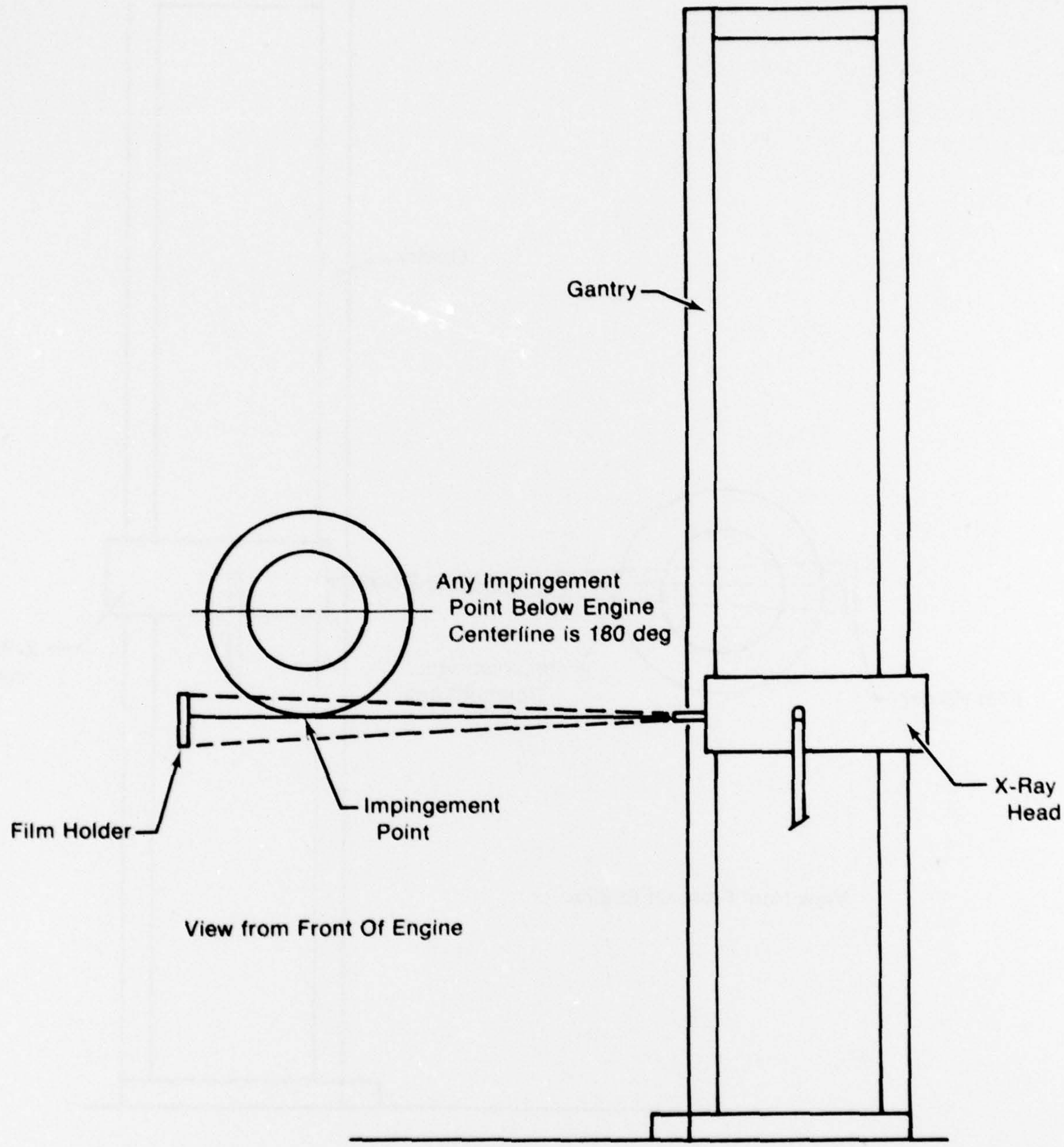

Figure 2. Setup for Taking Radiographs through Bottom Portion of Engine

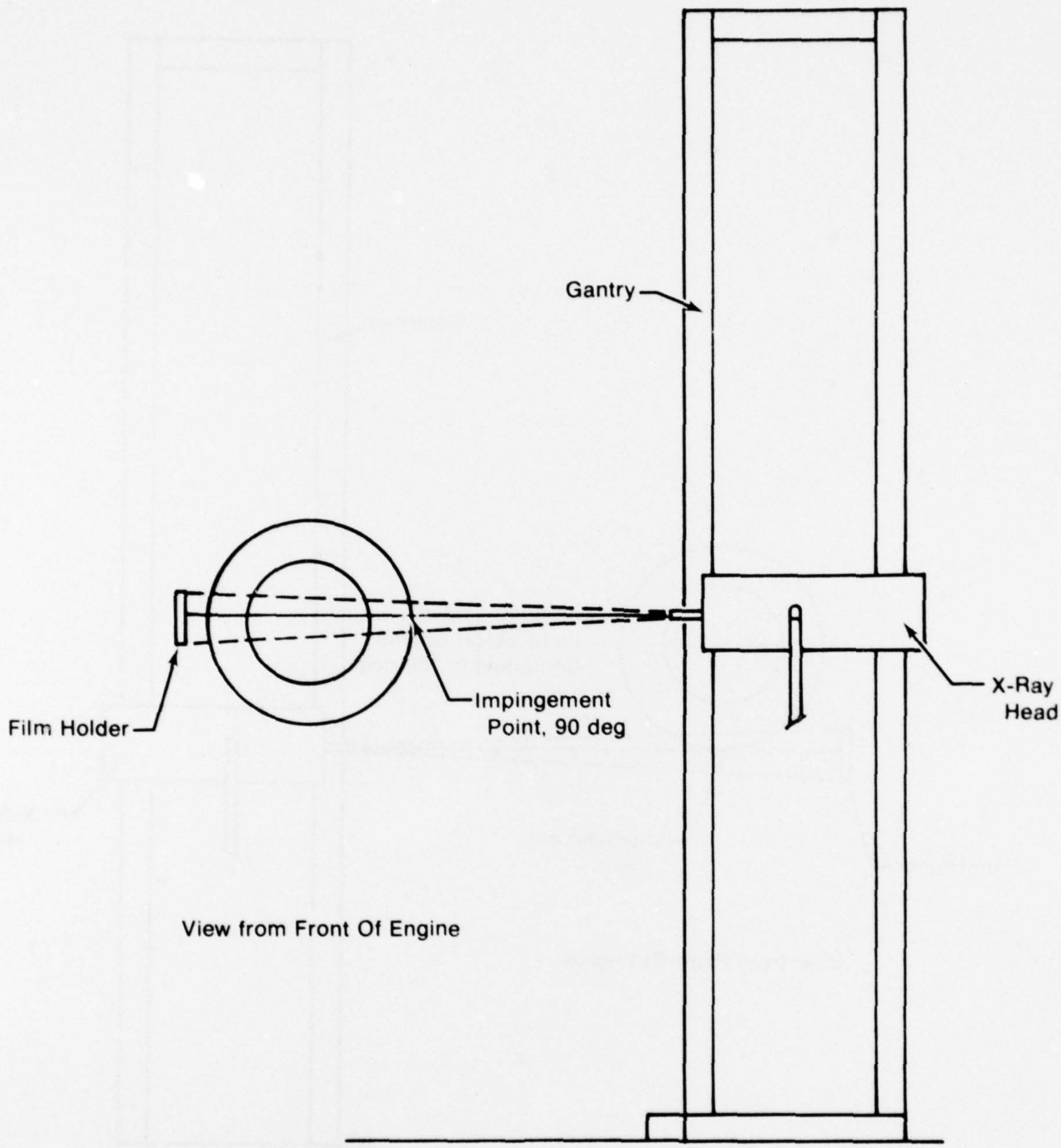

Figure 3. Setup for Taking Radiographs through Centerline of Engine

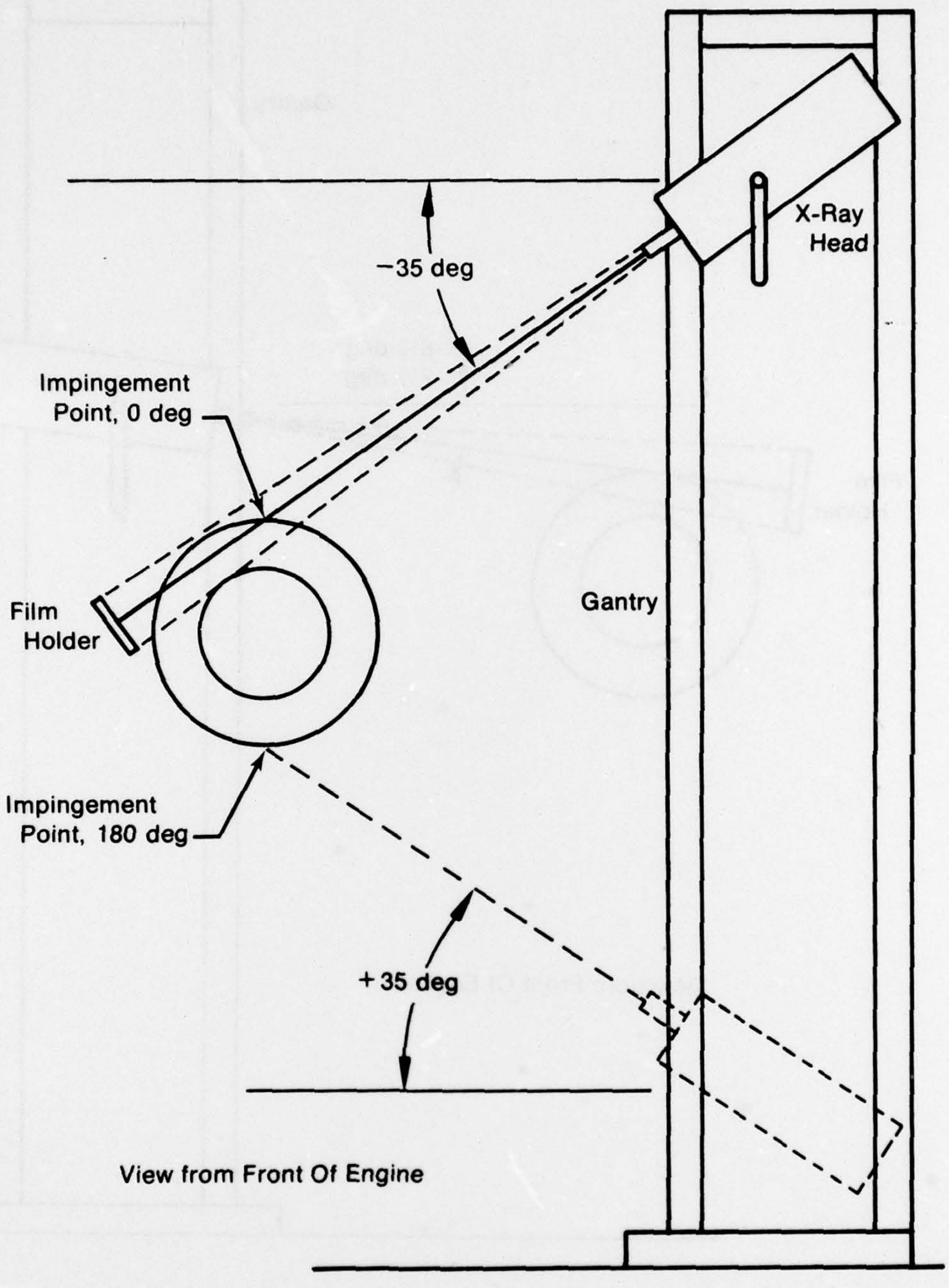

Figure 4. Angle Shots Used for Taking Radiographs of Combustor Support Pins

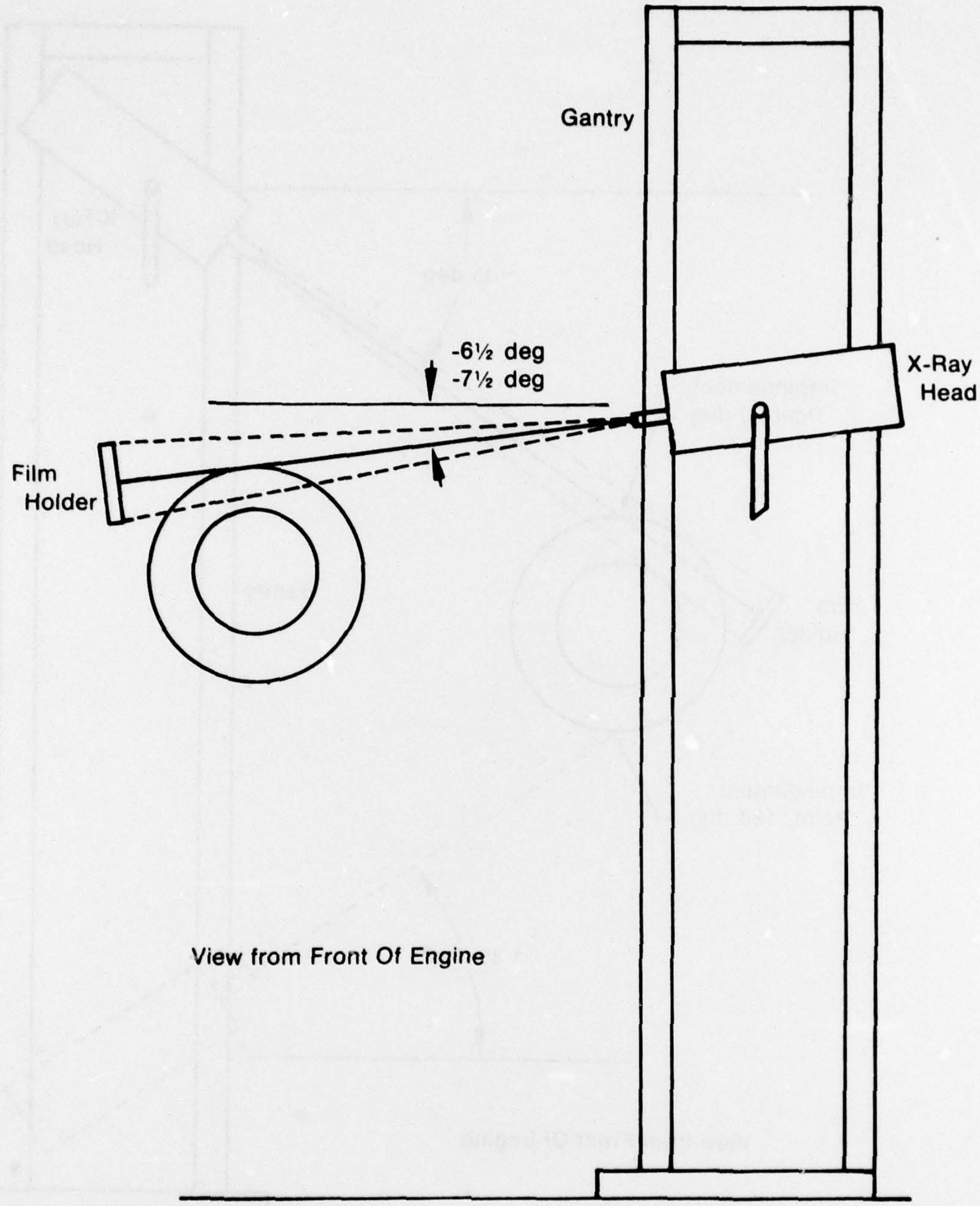

Figure 5. Angle Shots Used for Taking Radiographs of Fuel Nozzles

TABLE 2. SUMMARY OF RADIOGRAPHS TAKEN

	Number of Radiographs Taken			
Engine Condition	*Configuration 1*	*Configuration 2*	*Configuration 3*	*Total*
Cold Static	29	46	20	95
Steady-State	95	194	31	320
Snap Transient	43	168	133	344
Slow Transient	72	96	56	224
Hot Static	0	2	0	2
Total	239	506	240	985

TABLE 3. ENGINE LOCATIONS VIEWED BY VIDEO FLUOROSCOPY

Engine Location	*Top of Engine (0 deg)*	*Bottom of Engine (180 deg)*
Engine Configuration No. 2:		
Bumper Gap	X	X
Combustor Exit, Outer	X	X
First Nozzle	X	
Intershaft Clearance	X	X
Second Compressor Stator	X	
Engine Configuration No. 3:		
Bumper Gap	X	X
Combustor Exit, Outer	X	X
First Nozzle	X	X
Intershaft Clearance	X	X
Turbine Fourth Blade Root	X	
Turbine Fourth Blade Tip	X	
Turbine Third Blade Tip	X	
Turbine Third Blade Root	X	
Turbine Fourth Bearing Seal	X	
Gearbox		X
Compressor First Blade Root	X	
Compressor Fourth Blade Root	X	
Compressor Sixth Blade Root	X	
Turbine First Blade Root	X	
Turbine Second Blade Roor	X	

MOTION PICTURE

In conjunction with the test program a 13-minute color motion picture, with sound, was prepared.

The first part of the movie shows the test facility — the X-ray head in motion, the image fluoroscope, the film transporter, the engine test stand, and the control room. The narrative describes the operation of this equipment.

The second portion of the film outlines the reasons for the radiographic examination of the T55 engine and shows this program being carried out. The T55-L-712 engine and its water brake are shown being installed in the test facility. There are scenes of the control room and data reduction room during the test.

The third portion of the film describes the test results. Video fluoroscope tapes converted to film are shown, together with radiographs of the more significant findings, as selected by Army personnel. Overlays are provided to make the narrative clearer.

SECTION V

CONCLUSIONS

The radiographic examination of the T55-L-712 engine was successfully completed. The resulting radiographs and video fluoroscope tapes provided Army and Lycoming personnel with the data they required for a design review of the engine. The techniques employed in this program permitted determination of part clearances and displacements under various engine operating conditions, providing required information which could not be obtained by more conventional methods.

APPENDIX

RADIOGRAPHS OF LYCOMING T55-L-712 ENGINE

This appendix lists the radiographs of the Lycoming T55-L-712 engine taken by Pratt & Whitney Aircraft. Table A-1 lists the radiographs taken of engine configuration No. 1; Table A-2 lists the radiographs taken of engine configuration No. 2; and Table A-3 lists the radiographs taken of engine configuration No. 3. Each of these tables contains five columns. The differences in the engine configurations are only in the turbine section.

The first column identifies the engine location being examined.

The second column identifies the engine operating condition as follows:

CS	—	Cold Static
SS	—	Steady-State
SnT	—	Snap Transient
SlT	—	*Slow Transient*
HS	—	Hot Static.

The third and fourth columns identify X-ray positioning. Column three gives the impingement point (I.P.) of the X rays on the circumference of the engine in terms of radial angle as described in Section IV under the heading, "X-ray Locations." Column four indicates the angle at which the X rays move from the X-ray head to the impingement point — in most cases this angle is 0 degrees, indicating a horizontal path. In other cases, the angle above or below horizontal is indicated. A negative number of degrees indicates a downward X-ray path, while a positive number of degrees indicates an upward X-ray path.

The fifth column contains numbers which identify individual radiographs. In some cases the radiograph number is listed alone (example — 20, 21). In other cases, a reel number is listed, followed by a colon, after which are numbers identifying individual radiographs on that reel (example — R86: 1 through 8).

TABLE A-1.
RADIOGRAPHS OF ENGINE CONFIGURATION NO. 1

Engine Location	Engine Condition	X-ray Positioning: I.P. (deg)	X-ray Positioning: X-ray Angle (deg)	Radiograph Numbers
Compressor Section:				
First Stator	CS	0	0	20
	CS	180	0	21
	SS	0	0	R35: 1 through 11
	SS	180	0	R35: 12 through 20
Third Stator	CS	0	0	19
	CS	180	0	18
	SS	0	0	R36: 1 through 8
Sixth Blade	CS	0	0	16
	CS	180	0	17
	SS	0	0	R36: 9 through 16
Impeller	CS	0	0	15, 22, 23, 25
	CS	180	0	14
	SS	0	0	R36: 17 through 24
Turbine Section:				
First Blade	CS	0	0	1, 2, 13, 24, 26, 27
	CS	180	0	3
	SS	0	0	R28: 1 through 8
	SS	0	0	R29: 20 through 22
	SS	180	0	R34: 1 through 8
	SnT	0	0	R29: 1 through 8
	SnT	0	0	R29: 9 through 19
	SlT	0	0	R33: 1 through 24
Third Nozzle	CS	0	0	5
	CS	180	0	4
	SS	0	0	R28: 9 through 16
	SS	180	0	R34: 9 through 16
Third Blade	CS	0	0	6
	CS	180	0	7
	SnT	0	0	R30: 1 through 8 9 through 16
	SlT	0	0	R32: 1 through 24
Fourth Nozzle (Brg 4 & 5)	CS	0	0	9, 9A, 9B
	CS	180	0	8, 12
	SS	180	0	R34: 17 through 24
	SS	0	0	R28: 17 through 24
Fourth Blade	CS	0	0	10
	CS	180	0	11
	SnT	0	0	R30: 17 through 24
	SlT	0	0	R31: 1 through 24

TABLE A-2.
RADIOGRAPHS OF ENGINE CONFIGURATION NO. 2

		X-ray Positioning		
Engine Location	*Engine Condition*	*I.P. (deg)*	*X-ray Angle (deg)*	*Radiograph Numbers*
Compressor Section:				
First Blade	SS	0	0	R86: 1 through 8
	SnT	0	0	R86: 9 through 16
First Stator	SlT	0	0	R75: 1 through 24
	SnT	0	0	R76: 1 through 8
	SnT	0	0	R77: 1 through 8
	SnT	0	0	R78: 1 through 8
Second Blade	SS	0	0	R87: 1 through 8
	SnT	0	0	R88: 1 through 8
Fourth Blade	SS	0	0	R89: 1 through 8
	SnT	0	0	R89: 9 through 16
Sixth Blade	SS	0	0	R90: 1 through 8
	SnT	0	0	R90: 9 through 16
Impeller	CS	0	0	R80: 1 through 3
	SS	0	0	R91: 1 through 8
	SnT	0	0	R91A: 1 through 8
Turbine Section:				
First Nozzle	CS	0	0	37, 38, 39 40
	CS	180	0	53
	SS	0	0	
			0	
				R59: 1 through 8
	SlT	0	0	R60: 1 through 24
	SnT	0	0	R/S R63: 1 through 8
	SnT	0	0	R68: 1 through 8
First Blade	CS	0	0	44, 45, 46
	CS	180	0	52
	SS	0	0	R57: 17 through 24
	SS	180	0	R59: 17 through 24
	SlT	0	0	R62: 1 through 24
	SnT	0	0	R65: 1 through 8
	SnT	0	0	R66: 1 through 8
	SS	0	0	R94: 1 through 8
	SnT	0	0	R94: 9 through 16

TABLE A-2.
RADIOGRAPHS OF ENGINE CONFIGURATION NO. 2 (Continued)

Engine Location	Engine Condition	X-ray Positioning: I.P. (deg)	X-ray Positioning: X-ray Angle (deg)	Radiograph Numbers
Turbine Section (Continued):				
Bumper Gap	CS	0	0	41
	CS	180	0	51
	SS	0	0	R57: 9 through 16
	SS	180	0	R59: 9 through 16
	SlT	0	0	R61: 1 through 24
	SnT	0	0	R64: 1 through 8
	SnT	0	0	R67: 1 through 8
	CS	180	0	83
Second Blade	CS	0	0	42, 43
	SS	0	0	R58: 1 through 8
	SS	0	0	R95: 1 through 8
	SnT	0	0	R95: 9 through 16
Third Blade	SS	0	0	R96: 1 through 8
	SnT	0	0	R96: 9 through 16
Fourth Nozzle (Brg 4 & 5)	CS	0	0	47, 55
	CS	180	0	49, 56
	SS	180	0	R70: 1 through 8
Mechanical Section:				
1-3 Bearing	CS	90	0	72: 1 through 3
Second Bearing	CS	90	0	R81: 1 through 3
6-7 Bearing	CS	90	0	R71: 1 through 3
	SS	90	0	R84: 1 through 6
Gearbox	CS	180	0	R73: 1 through 3
	CS	180	0	79
	SS	180	0	R85: 1 through 8
Intershaft Clearance	SnT	90	0	R74A: 1 through 8
	SS	90	0	R74: 1 through 7
Combustor Section:				
Combustor Exit	CS	0	0	R82: 1
	CS	180	0	R82: 2
	SS	0	0	R92: 1 through 8
	SnT	0	0	R92: 9 through 16
	SS	180	0	R93: 1 through 8
	SnT	180	0	R93: 9 through 16
	SnT	0	0	R97: 1 through 8

TABLE A-2.
RADIOGRAPHS OF ENGINE CONFIGURATION NO. 2 (Continued)

Engine Location	Engine Condition	X-ray Positioning: I.P. (deg)	X-ray Positioning: X-ray Angle (deg)	Radiograph Numbers
Combustor Section: (Continued)				
Combustor Support Pin	CS	180	35	100, 101
	SS	180	35	102, 103, 104, 105, 106
	SS	0	−35	107, 108, 109, 110
	HS	180	35	111
Fuel Nozzle	CS	0	0	48, 54
	CS	180	0	50
	SS	0	0	R58: 9 through 16
	SS	180	0	R69: 1 through 8
	CS	0	−7½	98
	CS	0	−7½	99
	CS	0	−6½	112
	CS	0	−7½	113, 114
	SS	0	−6½	115, 116, 117, 118
	HS	0	−6½	119

TABLE A-3.
RADIOGRAPHS OF ENGINE CONFIGURATION NO. 3

Engine Location	Engine Condition	X-ray Positioning: I.P. (deg)	X-ray Positioning: X-ray Angle (deg)	Radiograph Numbers
Turbine Section:				
First Nozzle	SnT	0	0	R121: 1 through 5
	SS	0	0	127, 128, 129
	SnT	0	0	R130: 1 through 8
	CS	0	0	160
First Blade	SnT	0	0	R142: 1 through 8
	SnT	0	0	R143: 1 through 8
	CS	0	0	158, 159
Bumper Gap	CS	0	0	R120: 1
	CS	180	0	R120: 2
	SS	180	0	R120: 3 through 6
	SS	0	0	R120: 7 through 10
	SnT	0	0	R120: 11 through 18
	SIT	0	0	R122: 1 through 24
	SIT	180	0	R123: 1 through 24
	SnT	180	0	R124: 1 through 8
	SnT	0	0	R165: 1 through 11
Second Blade	SnT	0	0	R145: 1 through 8
	SnT	0	0	R146: 1 through 8
	CS	0	0	155, 156
Third Blade	SS	0	0	133, 134
	SnT	0	0	R148: 1 through 8
	SnT	0	0	R149: 1 through 8
	CS	0	0	135, 136, 152, 153
Fourth Blade	CS	0	0	137
	CS	0	0	138, 138A
	SnT	0	0	R139: 1 through 8
	SnT	0	0	R139A: 1 through 8
	SS	0	0	140
	SS	0	0	141
	SnT	0	0	R150: 1 through 8
	CS	0	0	151

TABLE A-3.
RADIOGRAPHS OF ENGINE CONFIGURATION NO. 3 (Continued)

Engine Location	Engine Condition	X-ray Positioning I.P. (deg)	X-ray Positioning X-ray Angle (deg)	Radiograph Numbers
Mechanical Section:				
1-3 Bearing	SS	90	0	R126: 1 through 8
	CS	90	0	161
Second Bearing	SS	90	0	R125: 1 through 6
Second Nozzle Seal	SS	0	0	131
	CS	0	0	157
	CS	0	0	162
	SnT	0	0	R144: 1 through 6
	SnT	0	0	144A, 144B, 144C
Third Nozzle Seal	SS	0	0	132
	SnT	0	0	R147: 1 through 8
	CS	0	0	154
Output Shaft	CS	90	0	163
	SnT	90	0	R164: 1 through 12